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YSSP Report
Young Scientists Summer Program

Projecting the contribution of assisted reproductive technology to completed cohort fertility

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Approved by

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Abstract

Assisted reproductive technology (ART) is having an increasing influence on the fertility trends of high-income countries characterised by a pattern of delayed childbearing. However, knowledge about the relationship between ART and completed fertility is limited and the extent to which delayed births are realized later in life through ART remains unexplored. Using data from Australian fertility clinics and national birth registries, the aim of this study is twofold: to project the contribution of ART for cohorts of women that have not yet completed their reproductive life; and to estimate the role played by ART in the fertility recuperation process. The proportion of children born after ART treatment is estimated to increase from 2.1% among women born in 1968 to 4.8-5.8% among women born in 1986. ART is projected to substantially affect the extent to which childbearing delay will be compensated at older ages, indicating that its availability may become an important factor in helping women to fulfil their reproductive plans later in life.

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About the author

Ester Lazzari holds a BSc and MSc in Economics and Social Sciences from Bocconi University and she is a final year PhD candidate in the School of Demography at the Australian National University. Her main research interests focus on the causes and consequences of late fertility, assisted reproductive technology and childlessness in low-fertility settings.
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Projecting the contribution of assisted reproductive technology to completed cohort fertility

Ester Lazzari

1. Introduction

In most high-income countries, childbearing is increasingly being postponed to later ages (Mills et al. 2011; Beaujouan & Sobotka 2017). Delayed parenthood is associated with lower completed fertility and with a higher chance of remaining permanently childless as reproductive capacity declines with age, especially among women, whose fecundity generally peaks in their mid 20s and declines rapidly in their mid to late 30s (Habbema et al. 2015; Schmidt et al. 2012). For instance, Leridon's simulation model (2004) shows that approximately 75% of women trying to conceive at age 30 will have a conception ending in a birth within one year, compared with only 66% at age 35, and 44% at age 40. With the increase in the proportion of couples experiencing age-related infertility, demand for medically assisted reproduction has also increased. Traditional forms of fertility treatments, such as ovulation induction and artificial insemination, continue to play a role in infertility care, however, assisted reproductive technologies (ART), such as in vitro fertilization (IVF), where the embryo is created in the laboratory and transferred into the uterus to achieve a pregnancy, now account for the majority of treatments with more than 2.5 million cycles performed globally each year (Chambers et al. 2021). Since the birth of Louise Brown in 1978, the first ART conceived child (Steptoe and Edwards 1978), treatment options for infertility have advanced dramatically in effectiveness and availability so that, over the past four decades, an estimated 6 million babies have been born worldwide as a result of ART treatments (de Mouzon et al. 2020).

Despite the ethical, legal and social challenges inherent to this technology (Brezina and Zhao 2012), ART has become a mainstream treatment for infertility and its contribution to total births has been slowly but steadily increasing. In 2019, one in 20 children born in Australia were the result of conception via ART (Newman et al. 2021). Similar figures can also be observed in some European countries, where an average of 3% of births are conceived through ART (Wyns et al. 2020), while in the United States, ART accounts for slightly less than 2% of total births (Centers for Disease Control and Prevention 2018). Although the development of ART has increased the chances of conception for couples with infertility, it cannot fully compensate for the age-related decline in reproductive potential because the effectiveness of ART is largely influenced by the number and quality of eggs available (Leridon 2017; Sartorius and Nieschlag 2010; McCarter et al. 2021).

One of the greatest challenges facing access to infertility care worldwide is the affordability of treatments which becomes prohibitive for many if it is not reimbursed through government or third-party insurance (Bitler and Schmidt 2012; Chambers et al. 2014; Hamilton and McManus 2012). Australia is characterized by a high ART utilization rate compared to international standards (Adamson et al. 2018), in part explained by the existence of a relatively supportive funding arrangement through Australia's universal healthcare system, Medicare. The scheme has covered approximately two thirds of total costs for an unlimited number of ART cycles (Commonwealth Government 2018), with no restrictions based on age or parity - limitations commonly in place in other countries (Allan et al. 2019).

The literature has drawn attention to the possibility of using ART as a potential policy tool to increase the fertility rate, comparable to other more traditional pro-natalist policies (Hoorens et al. 2007; Kocourkova and Fait 2009; Ziebe and Devroey 2008) and in some countries, policymakers have already explicitly acknowledged ART as a means to help the State to meet its ambition of higher population growth (Birenbaum-Carmeli and Dirnfeld 2008; Kim 2019; Tremayne and Akhondi 2016). Previous research has mostly focused on the impact of ART on overall fertility by adopting either period (Hoorens et al. 2007, Habbema et al. 2009) or cohort (Leridon 2017; Leridon and Slama 2008; Sobotka et al. 2008) approaches, showing a rather modest contribution of the order of 2-5%. Yet, the influence of ART greatly varies throughout a woman's reproductive life span, with more substantial contributions at older reproductive ages, and especially for very late conceptions. For example, in Australia, recent increases in period fertility rates at late (40+) reproductive ages have been largely driven by the increasing use of ART (Lazzari et al. 2021), suggesting that these procedures may in particular support fertility in a context of delayed childbearing.

The first contribution of the present study is to project completed cohort fertility (CFR) rates in Australia under alternative scenarios of plausible future uptakes of ART treatment and success rates. Australia represents an illuminating case study among the group of low-fertility countries as it has one of the highest ART utilization rates in the world (Chambers et al. 2021), while the adoption of a cohort approach provides a better estimate of the impact of ART to completed family size over time compared to period analyses. The second contribution is to investigate the role played by ART in increasing fertility rates at older reproductive ages by quantifying to what extent women that did not have children before the age of 30 can achieve such births later in life through ART. The concepts of postponement and recuperation suggest that fertility trends at any one age are linked: lower fertility at younger ages (postponement) is followed by higher fertility at older ages (recuperation). Hence, a cohort approach has the advantage of following these processes as they occur to the same group of women over their reproductive life course.

Unlike most other countries, the lack of an age limit for publicly funded access to fertility treatment places Australia in a unique position to investigate the contribution of ART at advanced reproductive ages. The findings will inform policymakers regarding the potential effect that publicly supported access to ART can have on the CFR and contribute to the existing knowledge by providing an in-depth study of ART use by age over a woman's reproductive life span.

1.1 Fertility trends and childbearing desires at older reproductive ages

Completed fertility of successive generations of Australian women has been steadily declining to an average of 2.0 children, slightly below the replacement level of 2.1, among women born in the years 1967-1971 (Lazzari 2021). Such decline was accompanied by a rise in permanent childlessness, from 9.6% for women born in 1950 to 15.2% for women born in 19681, and by a substantial change in the mean age at childbearing from 25.4 in 1971 (Australian Bureau of Statistics 2001) to 30.6 in 2017 (Australian Institute of Health and Welfare 2019), mainly driven by the postponement of first births (Carmichael 2013). Indeed, the proportion of women with no children aged 25–29 has increased from 42.8% in 1986 to 68.9% in 2016 and from 19.9% to 40.4% during the same period for women aged 30–34 years[1]. Since the beginning of the 1980s, the prevalence of very late (45+) births also increased: from 1.7% to 4.6% in 2018[1]. At the same time, similar changes occurred in other low-fertility countries (Beaujouan 2020; Billari et al. 2007), signalling the start of a period in which very-late entry into parenthood has become increasingly common. Moreover, repartnering has developed into a typical feature of the family system (Gray 2015), which further drives delayed childbearing.

[1] Own computations based on Australian Bureau of Statistics (ABS) data

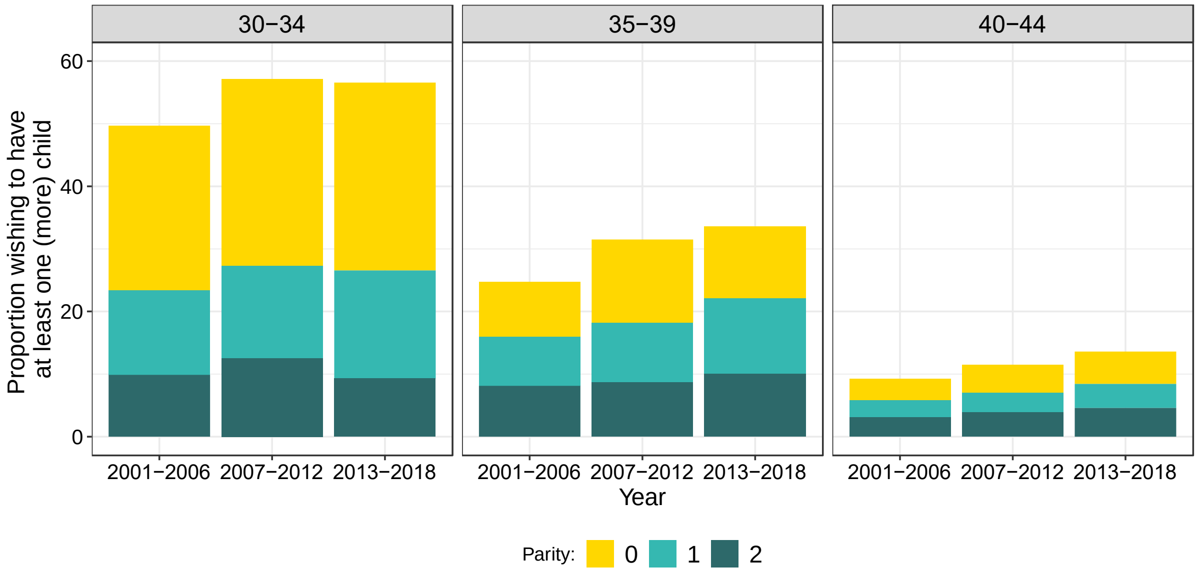

Fig. 1 *Share of women wishing to have at least one (more) child by age group and parity, Australia, 2001-2018.*

Source: Authors' computations based on Household Income and Labour Dynamics in Australia (HILDA) survey, waves 1-18, release 18 (weighted).

Shifts in the timing of fertility are also reflected in recent surveys of reproductive intentions, with substantial and rising shares of Australian women in their 30s or 40s wishing to have a child in the future. Specifically, Fig. 1 illustrates that increases in the proportion of women wishing to have at least one (more) child are more pronounced among those aged 35-39 (from 24.7% to 33.6%) and 40-44 (from 9.3% to 13.6%) and that, in almost all groups, desiring more children is associated with having one, or no children. The distinction between compositional factors (age and parity) is essential for interpreting trends in childbearing desires and their implications for ART use, as women typically resort to ART after their mid-30s and specifically to have a first child (Barbuscia et al. 2019; Lazzari et al. 2021; Stephen et al. 2017). Taken together, the increase in childbearing desires at advanced reproductive ages and the age-related decline in the biological capacity to reproduce, suggest that ART is likely to become more important for future fertility trends. Arguably, the increase in the prevalence of late births and rising use of reproductive technologies are linked (Billari et al. 2007), and ART may partly support fertility at older ages by helping women to fulfil their reproductive desires at an age when it is biologically most challenging.

To improve their chances of conception at older reproductive ages, women may consider preserving their fertility by freezing their eggs for future use. National registry reports show that egg freezing treatments make up only a small proportion of all ART treatments (2% in 2019) (Newman et al. 2021), however, there is evidence of a recent dramatic increase of 289% in the number of women using this procedure (Johnston et al. 2021). Similar increases took place in other high-income countries (Johnston et al. 2021; Quinton et al. 2021). If using own frozen eggs is not available, women of advanced reproductive age may have to consider alternative family building options, such as donated eggs. While most women prefer to have a genetic connection with their children (Daniluk and Koert 2012), at advanced reproductive ages this goal is less likely to be achieved due to reduced ovarian reserve (Hourvitz et al. 2009). In Australia, as in most other countries, the practice of using donor eggs is particularly common among women aged 45 and above, representing over 80% of total ART treatments at these ages (Newman et al. 2021).

2. Data and Methods

To predict the future contribution of ART to CFR, the model brings together information on three important aspects of change that may influence such contribution: 1) changes in the female population postponing childbearing and desiring to have children at advanced reproductive ages (when the risk of experiencing infertility is higher); 2) changes in the uptake of ART treatments; and 3) changes in ART success rates. Dependencies between these three components and ART and total births are shown in the causal loop diagram in Fig. 2. The total number of ART births is directly influenced by ART treatment rates (share of women receiving ART treatment) and ART success rates (share of women having an ART-conceived child after having received one or more treatments), and indirectly influenced by further childbearing postponement, which leads to a higher proportion of women seeking to have children at older ages when the reproductive potential diminished. ART treatment and success rates are also linked: an increase in the effectiveness of treatments encourages higher treatment rates, while an increase in the use of ART supports further advances in the technology. The total number of births is lowered by childbearing postponement, although ART births can partly compensate for it.

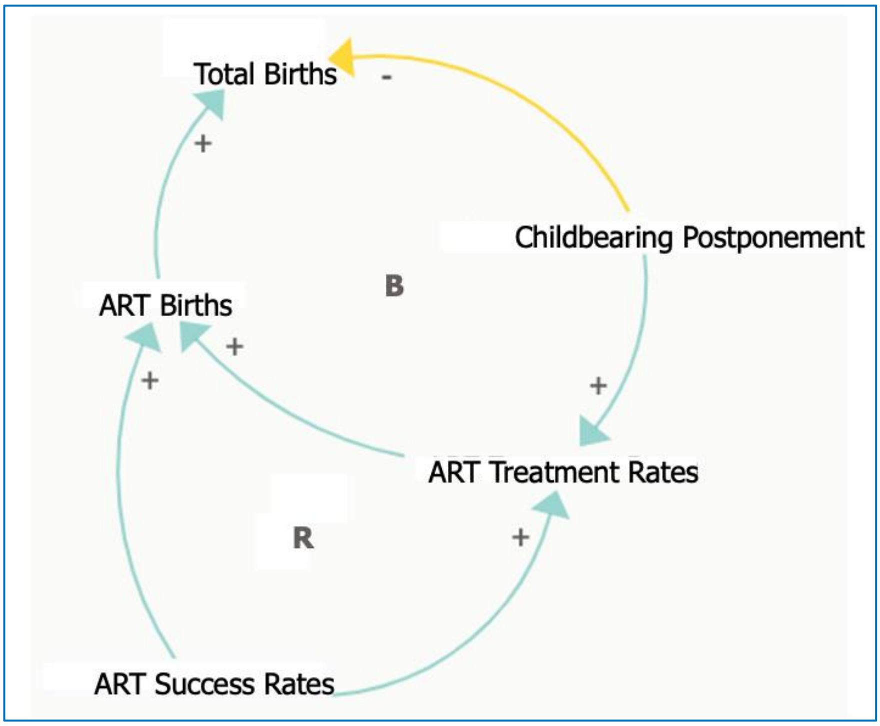

Fig. 2 *Causal loop diagram showing the contribution of ART treatment rates, ART success rates and childbearing postponement to the total number of births.*

Note: A balancing loop (B) stabilizes a component of the system while a reinforcing loop (R) reinforces such component.

2.1 Data sources

The number of ART births and treatments by single age of mother occurred in Australia between 2010 and 2017 are sourced in a de-identified format from the Australia and New Zealand Assisted Reproduction Database (ANZARD), a women-based clinical registry that collects information about all ART treatments conducted in Australia (Newman et al. 2021). All Australian fertility clinics are required to report ART birth outcome information to ANZARD as part of their licensing requirements; therefore, full registration of ART births can be assumed. To supplement this data, we collected information on the total yearly number of ART babies born to Australian women between 1998 and 2009 from the annual ANZARD reports. ART age-specific fertility rates for the period 1998-2009 are estimated assuming the same ART age-specific fertility profile observed in 2010. Fertility treatments that do not involve fertilization outside of the woman's body, such as artificial insemination (AI) and ovulation induction (OI), are not included, since only births resulting from treatments involving ART are reported in ANZARD. Population birth data are drawn from the national birth registries (ABS 2018). The number of non-assisted births (conceived without ART) is obtained by subtracting the number of ART-conceived births from the number of total births born in each year and by single-age of mother. The study takes a cohort approach and focuses on women born in 1968-1986. The fertility of the cohort born in 1968 is completed and known, while projecting is needed for later cohorts. All data on total and ART-related fertility occurring in 2018 and later are projected. Figure 3 provides a visual representation of the data sources and analyzed cohorts.

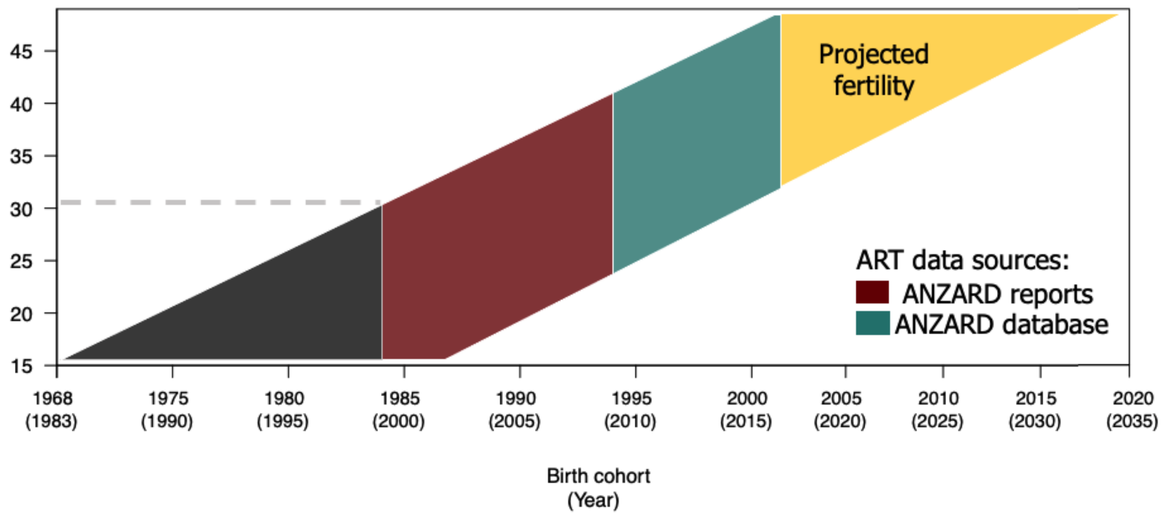

Fig. 3 *Lexis surface showing a representation of the data sources and analyzed birth cohorts.*

2.2 Methods

2.2.1 Modelling the role of ART on completed fertility

The completed fertility rate, or $CFR_c(x)$, of a cohort of women born in year c up to age x is computed as the sum of their age-specific fertility rates as:

$$CFR_c(x) = \sum_{x=15}^{49} f_c(x) = \frac{B_c(x)}{W_c(x)} \tag{1}$$

where $B_c(x)$ is the number of births to women at age x born in year c, and $W_c(x)$ is the number of women in the population at age x born in year c. In order to study how ART influences the $CFR_c(x)$, Eq. (1) is reformulated as the sum of ART and non-ART age-specific fertility rates, as:

$$CFR_c(x) = \sum_x (f_c^{ART}(x) + f_c^N(x)) = \sum_{x=15}^{49} \left(\frac{B_c^{ART}(x)}{W_c(x)} + \frac{B_c^N(x)}{W_c(x)}\right) \tag{2}$$

where $B_c^{ART}(x)$ indicates births conceived through ART and B_c^Nindicates births conceived without ART. ART age-specific fertility rates can be further decomposed as:

$$\sum_x f_c^{ART}(x) = \sum_x f_c^T(x)\, f_c^S(x) \tag{3}$$

where

$$f_c^T(x) = \sum_{x=15}^{49} \frac{T_c^{ART}(x)}{W_c(x)} \tag{3.1}$$

corresponds to the ART age-specific treatment rate (the proportion of women of age x born in year c receiving ART treatment out of all women of age x born in year c in the population) and

$$f_c^S(x) = \sum_{x=15}^{49} \frac{B_c^{ART}(x)}{T_c^{ART}(x)} \tag{3.2}$$

corresponds to the ART age-specific success rate (the number of ART-conceived babies born to women of age x and born in year c out of all women of age x born in year c receiving ART treatment).

The decomposition in Eq.(3) is suitable for the purpose of analyzing the importance of both a change in the demand for ART children and in success rates in determining the contribution of ART to age-specific fertility rates. This way of measuring success rates differs from the medical literature, where success is typically computed as the ratio of the number of treatment cycles to live births. Instead, this method reflects the age-specific probability that a woman undergoing ART treatment in a given year will be successful in having a desired birth. An increase in the average number of treatments received by the same patient would lead to an increase in success rates that is not driven by further technological improvements, nor by an increase in the proportion of women treated. Hence, an assumption of our model is that the number of cycles performed by each woman has not substantially changed over time.

2.2.2 Cohort fertility forecasting

The forecasting of the CFR is accomplished by using the five-year extrapolation method by Myrskylä et al. (2013), which is designed to estimate completed cohort fertility where there is incomplete information available. In a recent assessment of twenty methodologies to forecast CFR, this five-year extrapolation method has been evaluated to be the most accurate, and to outperform more sophisticated forecasting models (Bohk-Ewald et al. 2018). This method is also preferred to the simpler freeze-rate approach, which assumes that the next age-specific fertility rates will follow the same trend of the most recent year, and, hence, it can produce misleading estimates when the timing of fertility is changing over time. The method extrapolates the trend in period age-specific fertility rates five years into the future based on the five-previous years, and then freezes the rates (Myrskylä et al. 2013). This corresponds to assuming that the trend towards childbearing delay in Australia will continue after 2017 (the most recently observed year) until 2022.

2.2.3 Projection scenarios of ART fertility rates

In combination with the non-assisted forecasted cohort fertility rates described above, five alternative scenarios are formulated, based on different assumptions regarding future ART success rates and treatment rates (in Fig. 4), and added to the non-assisted forecasted cohort fertility rates to create five projections of future completed fertility.

Scenario 1 (S1): *No-change*. After 2017 there is no further improvement in success rates and no further increase in treatment rates. In other words, success and treatment rates remain constant at their level last observed in 2017.

Scenario 2 (S2): *Extrapolated success rates*. Success rates are extrapolated five years into the future, from 2018 to 2022, and are kept then fixed at their latest extrapolated level. Treatment rates remain fixed at the level last observed in 2017. This means that the future demand for ART remains unchanged, and further increases in the number of ART births are only the consequence of improvements in the technology.

Scenario 3 (S3): *Extrapolated treatment rates*. This scenario envisages increasing demand for ART by future cohorts as they age. Treatment rates are extrapolated five years into the future, from 2018 to 2022, and are then kept fixed at their latest extrapolated level. Success rates remain unchanged after 2017.

Scenario 4 (S4): *Extrapolated success and treatment rates*. Both success and treatment rates are extrapolated five years into the future, from 2018 to 2022, and are then kept fixed at their latest extrapolated level.

Scenario 5 (S5): *Egg donation and freezing*. This hypothetical scenario takes into account the rising availability and use of third-party donor eggs as well as the rising number of women choosing to freeze their eggs at a younger age in order to use them at later reproductive ages. Elective egg freezing was not widely accessible until recently but in the past few years increased used of donor eggs among women aged 45-49 has led to a sharp increase in success rates in this age group. If also younger women were to embrace the use of this option, we may see more substantial improvements in ART success rates also at less advanced reproductive ages in the future than envisaged by previous scenarios. We make a modification in the extrapolation of success rates by age. By age 40 the extrapolated success rates over the period 2018-2022 are the same as in Scenario2 and 4 but success rates at age 40 and above are kept fixed at their average extrapolated level at age 45-49 (i.e. 25%). Treatment rates are extrapolated the same way as in Scenario 3 and 4.

In our view, Scenario 4 is the most realistic one, while Scenario 1 should be seen as a benchmark to evaluate changes compared to a situation where there were no further increases in the demand for ART and no further improvements in ART success rates. Scenarios 2 and 3 are useful to disentangle the effect of an increase in ART treatment and success rates, but it is unlikely that one will occur without the other. Scenario 5 describes a less plausible situation and it is not indicative of what will be experienced by the 1968-1986 cohorts, as it is unlikely that all women aged 40 and above will suddenly shift from using own fresh eggs to using frozen or third-party donor eggs after 2017. However, it provides insights of what could happen to the contribution of ART to the CFR if the practice of using younger eggs (either own previously frozen or from a donor) becomes more widespread. While supply constraints and ethical concerns may prevent donor eggs from growing in popularity (Gleicher et al. 2020), recent evidence suggests that there has been a dramatic increase in the utilization of egg-freezing in Australia (Johnston et al. 2021). Moreover, the demographics of women choosing to freeze their eggs is shifting to a younger age group, which is closer to the biologically optimal age (Human Fertilization and Embryology Authority 2018; Johnston et al. 2021), supporting the idea that egg-freezing is likely to become more important for future fertility trends.

Ideally, changes in educational composition and in the corresponding assisted and non-assisted fertility patterns should also be taken into account. Highly-educated women are more likely to delay family formation and hence they are at higher risk of experiencing infertility and of using ART. Between the cohorts of women born in 1968 and 1986 there has been a substantial educational expansion, with the proportion of tertiary educated women increasing from slightly less than 30% to 45% (see the supplemental material for further details). Moreover, disparities in the use of ART have been found across different socio-economic groups, even after controlling for the need for service (Harris et al. 2016). In order to take into account such heterogeneity and as a robustness check, we performed a sensitivity analysis in which we evaluated the usefulness of incorporating educational attainment in the projection model (see the supplemental material). Compared to the results presented in this paper, no major differences were found.

2.2.4 Projection scenarios of ART contribution to fertility recuperation

The method developed by Sobotka et al. (2012) is used to investigate how ART births have affected the postponement and recuperation processes. In particular, we compared the gap in cumulative CFR at different ages between an older (reference) cohort and subsequent birth cohorts. In the postponement phase, the cumulative CFR of successive cohorts is lower compared to that of the reference cohort, while in the recuperation phase the cumulative difference gradually decreases. In particular, since the utilization of ART before the onset of the recuperation phase is almost null, this method allows to quantify to what extent delayed births are realized at later ages because of ART. Such contribution during the recuperation stage is computed for all cohorts as the percentage of CFR that has been achieved since the age of 30 compared to the reference cohort as a consequence of ART utilisation. Although in Australia the process of fertility delay and recuperation started among women born in the late 1940s[2], the fertility profile of the cohort born in 1968 is used as reference, as the focus of this paper is on the recuperation process of the following 18 birth cohorts.

2.3 Reasons for caution

When estimating the potential impact of ART on the CFR, there are a number of assumptions and potential limitations that should be taken into account. First, the study assumes that births conceived through ART would not have happened without the treatment. However, the availability of ART might have supported provision of treatment to couples that would have eventually conceived without it (Cahill et al. 2005; de La Rochebrochard et al. 2009; Troude et al. 2012), leading to an overestimation of the actual impact of ART. Second, the availability of ART might have encouraged couples to delay childbearing, particularly for people unaware of the risks such as age-related infertility (Abramowitz 2014 and 2017; Rainer et al. 2011), hence shifting reproduction to ages where the chances of conception are lower. In contrast, there is also evidence suggesting that affordability of ART treatment

[2] In Sobotka et al. 2012, the cohort of onset of postponement corresponds to the first cohort to have experienced an increase in the mean age at childbearing that spanned for at least five consecutive cohorts.

might encourage couples to seek help sooner rather than later (Kocourkova et al. 2014). Third, the higher incidence of multiple births associated with ART deliveries as compared to non-ART deliveries may also lead to an amplification of the contribution of ART to fertility rates. While there has been a sharp decrease in the ART multiple birth rate in Australia, from a peak of 22.1% in 2000 (Dean and Sullivan 2003) to 2.9% in 2017 (Newman et al. 2021), this is still higher than the proportion of multiple deliveries from all conceptions of 1.5% (Australian Institute of Health and Welfare 2019) and it indicates that for all cohorts, but especially among older cohorts, the contribution of ART to completed fertility is partially attributable to the higher incidence of duplets and triplets births. Another concern is that, we do not know yet the effect of the outbreak of the the COVID-19 pandemic on the provision and uptake of fertility treatments to Australian couples (Rodriguez-Wallberg and Wikander 2020). The impact on our projection model depends on the extent to which different ART utilization rates during the COVID-19 pandemic have affected the quantum of ART related fertility, while the adoption of a cohort approach eliminates the bias induced by transitory changes in fertility timing.

3. Results

3.1 Age-specific treatment and success rates

Estimated (2006-2009), observed (2010-2017) and projected (2018-2022) trends in ART success rates and treatment rates used in the projection model are displayed in Fig. 4. Between the ages of 30 and 45, success rates gradually decline with age: while approximately 40% of treated women in their early 30s can expect to give birth to an ART child, by the age of 45 this proportion has considerably declined. Since 2011, however, success rates at age 45 and above increased rapidly. This has produced a rebound in success rates at very old reproductive ages, attributable not only to technological improvements, but also to the increasing popularity of alternative treatment options, such as third-party egg donation and elective egg-freezing. For example, only 3% of women receiving ART treatment had a birth at age 49 in 2011, 20% in 2017 and 35% in 2022. The distribution of age-specific treatment rates (Fig. 4-B) highly resembles that of total age-specific fertility rates, although with an older age profile. It is projected that treatment rates per 1,000 women at age 35-40 will increase from an average of 18 in

2006 to 26 in 2022. The mean age at treatment is also projected to slightly increase, from 35.6 in 2006 to 36.4 in 2022.

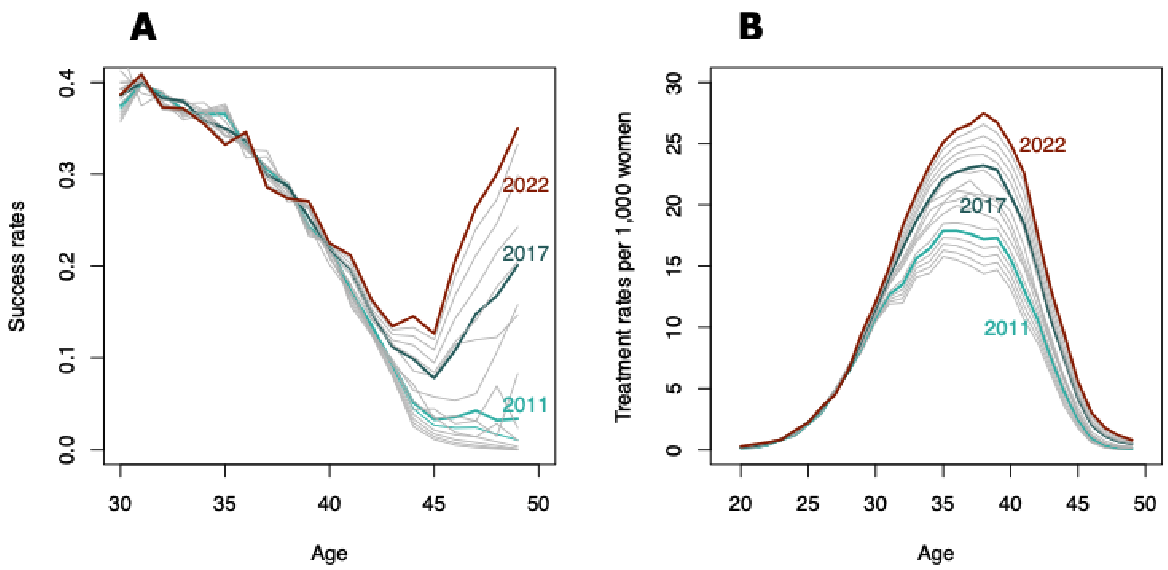

Fig. 4 *Estimated (2006-2009), observed (2010-2017) and projected (2018-2022) ART age-specific success rates (A) and ART age-specific treatment rates (B).*

Source: Authors' computations based on ANZARD and ABS data. Note: Results are obtained using Eq. (3).

3.2 Trends in completed cohort fertility

Figure 5 features the observed and projected CFR for the 1968-1986 birth cohorts in Australia according to the *No-change Scenario* and to a hypothetical situation where no ART treatment was available. The projection suggests that there will be a slight decline in CFR and that on average women born in 1986 will have 1.9 children, which is an all-time low in Australia, although still above the "very-low" fertility threshold suggested at 1.75 (Zeman et al. 2018). The decline in CFR would be more substantial in the absence of fertility treatment: without births resulting from ART, the CFR of the 1986 cohort would be 1.8, approximately 5% lower than its total projected CFR. The contribution of ART is likely to increase over time, signalling that ART will become particularly important for women that are currently in the early stage or in the middle of their reproductive life (30 years old and younger).

When the share of ART births out of total births is broken down by age group and single birth cohort (Fig. 6), the overall pattern of results shows that if the success and treatment rates continue to increase (S4) the probability of having a child conceived through ART increases with age and tends to be higher among more recent cohorts. For instance, the proportion of ART-conceived children among women aged 40-44 increases from 11.9% in the 1968 cohort to 25.3% in the 1986 cohort, and from 7.8% to 37.1% between the same cohorts for women aged 45-49. This pattern reflects the greater reliance on ART to fulfil childbearing desires at advanced reproductive ages and the increasing demand for ART as a family building option across generations. A less substantial increase is obtained using the *Extrapolated treatment rates Scenario* (S3) (not shown), with the proportion of ART-conceived children increasing to up to 23.0% for women aged 40-44 and 21.1% for women aged 45-49 born in 1986.

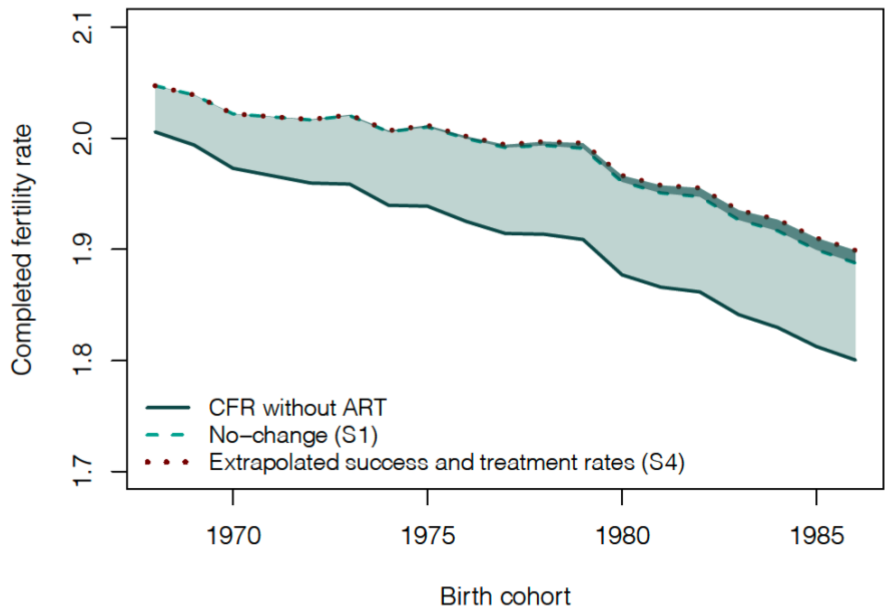

Fig. 5 *Observed (1968) and projected (1969-1986) completed cohort fertility, selected scenarios.*

Source: Authors' computations based on ANZARD and ABS data.

In Fig. 7, we present the projected percentage contribution of ART use on CFR according to five different scenarios (the underlying numbers are shown in Table 1). All scenarios indicate a gradual increase in the impact of ART on the CFR. The *No-change Scenario* (S1), which assumes no further change in success and treatment rates (i.e. keeps age-specific success and treatment rates fixed after 2017), results in a contribution of ART of up to 4.6% for the cohort born in 1986. The *Extrapolated success rates Scenario* (S2) leads to an impact of 4.8% for the most recent cohort, while the *Extrapolated treatment rates Scenario* (S3) shows a more substantial contribution (5.2% for the 1986 cohort), suggesting that the increasing role of ART in fueling the CFR will be mainly the result of an increase in the demand for treatment rather than of further technological improvements.

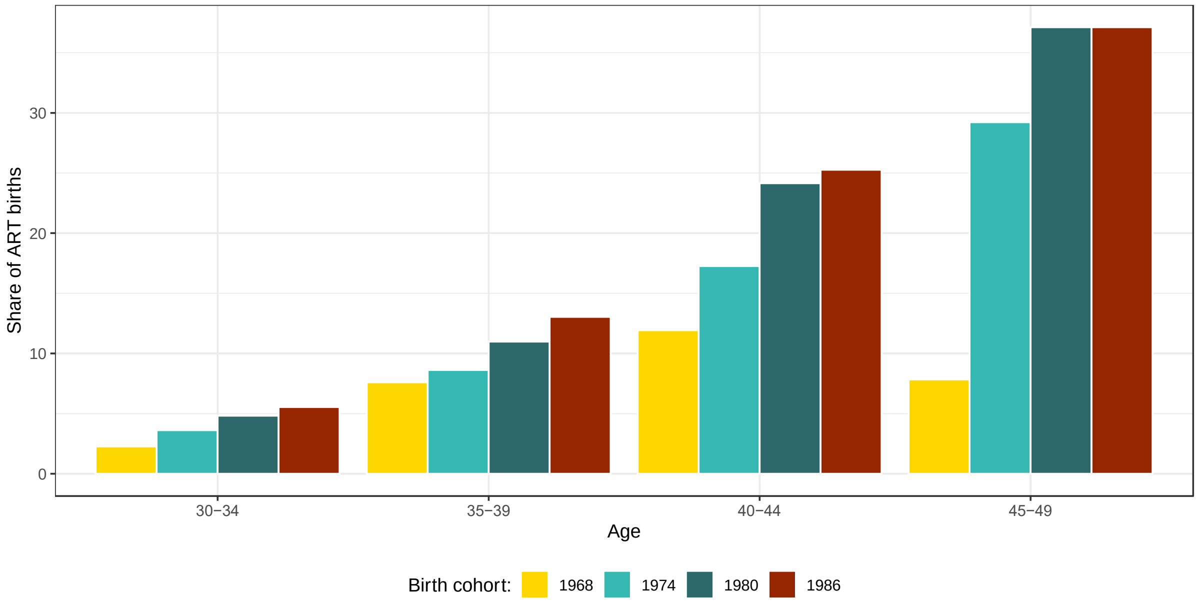

Fig. 6 *Observed (1968) and projected (1969, 1974, 1980, 1986) percentage contribution of ART to age-specific fertility rates.*

Note: Projected values are obtained using the Extrapolated success and treatment rates Scenario (S4).

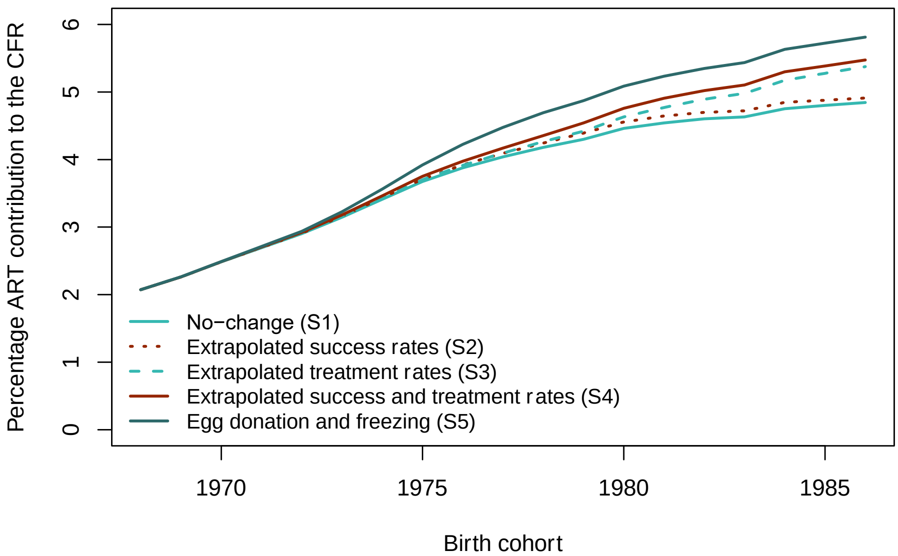

Fig. 7 *Observed (1968) and projected (1969-1986) percentage ART contribution to CFR.*

Source: Authors' computations based on ANZARD and ABS data.

The *Egg-donation and freezing Scenario* (S5) sits apart from the other scenarios shown because of its greater contribution to CFR (almost 6% for the 1986 birth cohort). Despite being not representative of what will be likely experienced by the analysed cohorts of women, it sheds light on what could happen to the contribution of ART to the CFR if the practice of using younger eggs becomes more influential. From the comparison of all scenarios, it emerges that the contribution of ART is relatively similar for the 1969-1975 cohorts, while it gradually becomes more distinct for women that were younger than 42 years at the projection baseline. This can be explained by the fact that, among the older cohorts of women included in this analysis, ART treatments were relatively less common and successful, which attenuates the contrasts across scenarios.

Table 1 *Estimated percentage effect of ART use on the CFR according to five scenarios, Australian women born 1968-1986.*

Birth cohort	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
1968	2.07	2.07	2.07	2.07	2.07
1969	2.26	2.26	2.26	2.26	2.26
1970	2.49	2.49	2.49	2.49	2.49
1971	2.69	2.70	2.70	2.70	2.71
1972	2.90	2.91	2.91	2.92	2.94
1973	3.15	3.16	3.16	3.18	3.23
1974	3.41	3.44	3.43	3.46	3.56
1975	3.68	3.71	3.70	3.75	3.92
1976	3.88	3.92	3.91	3.98	4.23
1977	4.04	4.09	4.10	4.17	4.48
1978	4.18	4.24	4.27	4.36	4.69
1979	4.30	4.39	4.42	4.54	4.87
1980	4.46	4.56	4.63	4.76	5.09
1981	4.54	4.65	4.77	4.91	5.24
1982	4.61	4.70	4.89	5.02	5.35
1983	4.63	4.72	4.98	5.11	5.44
1984	4.75	4.85	5.17	5.30	5.63
1985	4.80	4.88	5.28	5.39	5.72
1986	4.85	4.91	5.38	5.48	5.81

Source: Authors' computations based on ANZARD and ABS data.

3.3 Completed fertility recuperation

Figure 8 illustrates the projected dynamics of the postponement and recuperation processes for three selected cohorts (1974, 1980, and 1986), as compared to the reference cohort born in 1968. Supplementary information – such as the projected decline in CFR by age 30 and its percentage recuperation – are shown in Table 2.

Table 2 *(a) Projected decline in completed fertility by age 30 for cohorts born in 1980, 1982, 1984 and 1986, with and without ART; (b) Projected recuperation in completed cohort fertility for cohorts born in 1980, 1982, 1984 and 1986, with and without ART.*

	Birth cohort		
Year of birth	**1974**	**1980**	**1986**
Age at forecast in 2017 (a) Projected decline in CFR by age 30*	35	33	31
without ART	0.176	0.221	0.270
Scenario 1	0.169	0.209	0.257
Scenario 4	0.169	0.209	0.257
Scenario 5	0.169	0.209	0.257
(b) Projected recuperated CFR* (in %)			
without ART	62.5	41.7	26.8
Scenario 1	100.1	78.5	57.0
Scenario 4	100.7	81.2	61.4
Scenario 5	101.8	84.1	63.8

*As compared to the completed fertility of the benchmark cohort (1968), non-ART births only.
Source: Authors' computations based on ANZARD and ABS data.

With age, ART has had an increasingly important role in offsetting the decline in CFR. While some recuperation between the ages of 30 and 40 is happening regardless of ART, after the age of 40, the increase in ART conceived births becomes the only driver of further recuperation. For the 1974 cohort, fertility recuperation is complete when ART births are taken into account. For the cohort of women born in 1980 and 1986, 78.5- 84.1% and 57.0-63.8% of delayed fertility will be realized after the age of 30, respectively, as compared to the reference cohort, with approximately half of such recuperation attributable to ART. Hence, while the use of ART substantially contributes to women having births at older reproductive ages, it cannot fully prevent the decline in CFR. As expected, the contribution of ART is mostly concentrated in the recuperation phase (at age 30 and above).

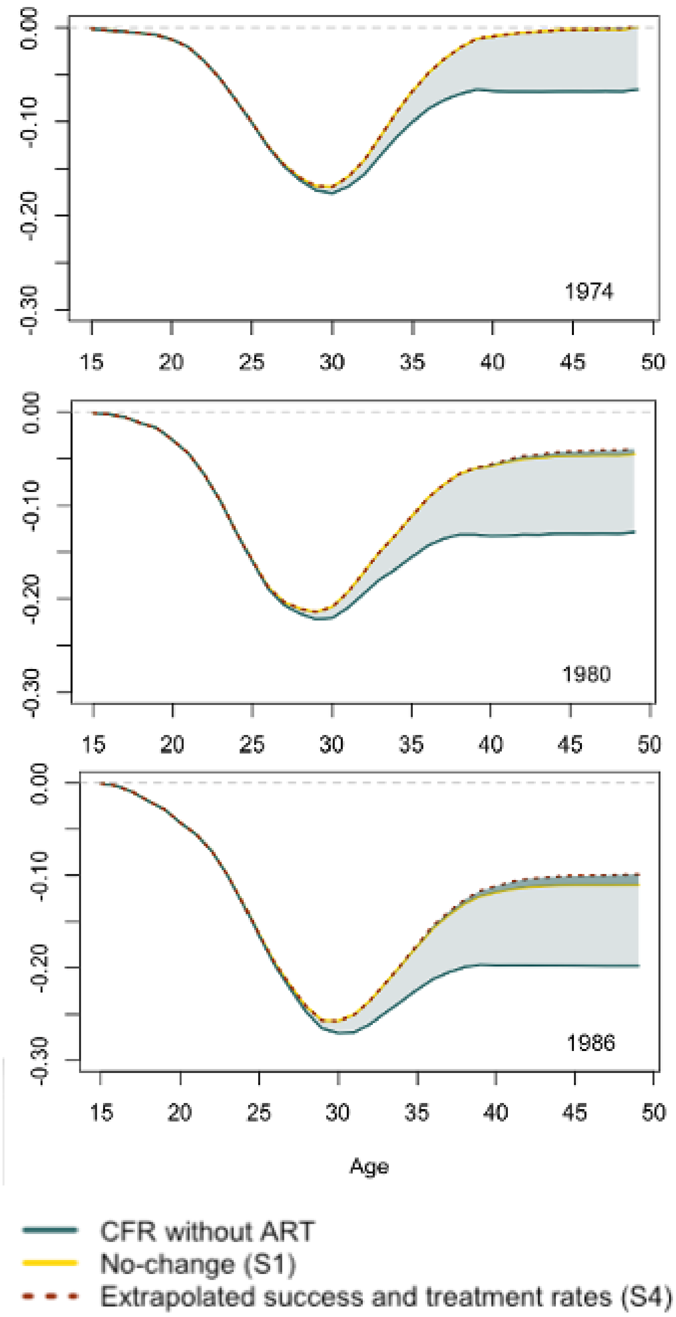

Fig. 8 *Projected cumulated cohort fertility of women born in 1974, 1980, 1986 compared to the observed reference cohort (born in 1968).*

Source: Authors' computations based on ANZARD and ABS data. Note: Completed fertility of the reference cohort does not include ART births.

4. Discussion and Conclusion

Using data from a comprehensive clinical registry of ART treatments and births, the present study projects the contribution of ART to the CFR in Australia under five alternative scenarios. The proportion of children born after ART treatment is estimated to increase from 2.1% among women born in 1968 to 4.6-5.8% among women born in 1986. The overall pattern of results shows that the probability to have an ART conceived child increases with age and across cohorts. Specifically, in the 1980-1986 cohorts, approximately a third of children born to women aged 45-49 and a fourth of children born to women aged 40-44 are expected to be the result of conception via ART. Our findings are robust across scenarios and the adoption of a cohort approach implies that results are not sensitive to short-term changes in treatment rates and success rates introduced by temporary shocks. Even in the most conservative *No-change Scenario* (S1), in which we assumed that there will be no further increases in the demand for ART nor improvements in the effectiveness of treatments after the last observed year, the contribution of ART is substantial and increasing. Our results suggest that increases in ART-related fertility rates will be mainly driven by an increase in the demand for treatment rather than by further technological improvements. However, the increasing popularity of alternative treatment options, such as elective egg-freezing and the use of third-party donor eggs, may alter these dynamics in the future. Beyond presenting a plausible picture of the contribution of ART to the CFR, the goal of this paper is to explore how ART contributes to fertility recuperation. It was found that ART will largely affect the extent to which postponed childbearing will be compensated at older ages and that, compared to a hypothetical situation where no ART treatment is available, the fertility recuperation for cohorts of women currently in their early to mid-30s is almost double. One notable set of findings is that after the age of 40, the increase in ART conceived births becomes almost the only driver of further fertility recuperation.

The in-depth study of ART use by age appears essential for evaluating current and future fertility trends in low-fertility countries. So far, these aspects have been surprisingly absent in many discussions of the demographic contribution of ART, as most previous research focuses on the impact of assisted reproduction on overall fertility (Hoorens et al. 2007, Habbema et al. 2009; Leridon 2017; Leridon and Slama 2008; Sobotka et al. 2008). Yet, our results provide support for the existence of a substantial contribution of ART at older reproductive ages and corroborate previous research demonstrating the key role played by ART in increasing period fertility rates after the age of 40 (Lazzari et al. 2021).

Some caution should be taken in interpreting these results. First, it is possible that some ART conceived births would have happened without the treatment, leading to an overestimation of the actual impact of ART. Second, the higher incidence of multiple births associated with ART deliveries as compared to other deliveries may also lead to an overestimation of the demographic contribution of ART. Third, the availability of ART may trigger unintended behavioural responses by encouraging women to stay childless for longer (Abramowitz 2014 and 2017; Rainer et al. 2011), hence increasing their risk of experiencing infertility and of underachieving their reproductive plans. This may be particularly relevant considering the existence of widespread misconceptions regarding the biological limits to reproduction and the ability of ART to restore lost fertility (Pedro et al. 2018). Aware of these uncertainties, our projections are based on rather conservative estimates regarding future demand for ART, technological changes and childbearing postponement.

These patterns should be seen as part of a major change in the family formation process in most low-fertility countries, including Australia, involving the postponement of childbearing to older reproductive ages (Beaujouan & Sobotka 2017). More women are having children after the age of 30 as a result of their delay of the steps leading to family formation and their engagement in second or higher order unions (Thomson et al. 2014), which has led them to reproduce at later ages with new partners (Beaujouan and Solaz 2012). Shifts in the timing of fertility have been accompanied by a substantial increase in the proportion of women in their 30s or 40s wishing to have (more) children, indicating that future fertility levels will largely depend on the ability of women to realize their childbearing desires at these advanced reproductive ages. However, the strong age-related decline in the realization of childbearing plans (Beaujouan et al. 2019) suggests that the share of women achieving a reduced family size compared to their ideal or remaining involuntarily childless will also increase. In light of this analysis, the provision of ART treatments can help to reduce the gap between wished and achieved number of births as it provides an opportunity to reconcile differences between the desired and biologically optimal age to have children by increasing the chances of conception at older reproductive ages.

We speculate that egg-donation and elective egg-freezing may become more popular treatment options in the future and, in turn, increase the contribution of ART to the CFR. In particular, elective egg freezing offers an opportunity to alleviate the pressure of the biological clock by extending the time-span available for having a genetically related child. Despite a sharp increase in utilization in recent years, egg-freezing remains an expensive medical procedure, that it is not typically covered by Medicare. Future policy changes and employer-sponsored egg freezing, following the example of Apple and Facebook (Friedman 2014), may alter this situation.

The provision of more affordable ART treatments is an enlighted policy, that has been shown to increase access to treatment of those in need, reduce multiple pregnancy rates and reduce the costs per live birth (Vélez et al. 2014). However, more research needs to be done to understand whether ART also provides a potential policy instrument to raise, or mantain fertility levels (Mladovsky and Sorenson 2009). Women should be advised of the decline in fecundity with age (Menken 1985) so to avoid reliance on ART as a means to have children, if an alternative option is possible. However, one of the main reasons for elective egg freezing is the inability to find a partner, or a partner who wishes to have a child (Pritchard et al. 2017). This suggests that people do not necessarily postpone parenthood by choice, and that a dominant reason for using ART is as a response to life factors which have interrupted the reproductive life course.

The increasingly narrow window for parenthood that exists between when women start trying to form a family and the end of their reproductive life increases the risk that childbearing plans will not be realised. Other things being equal, for those couples unable to achieve a pregnancy spontaneously, increased use of ART treatments may compensate for their reduced fecundity and success rates, and in turn increase the CFR. Billari et al. (2007) concluded that "the upper age limit of fertility has been pushed toward new extremes, very likely as a result of the advances in reproductive technology". Yet, an effort to empirically analyse the contribution of ART for late and very late fertility trends is only starting to emerge in the demographic literature. This paper highlights the important role of ART in increasing fertility rates at old reproductive ages and, hence, in the fertility recuperation process, particularly among younger generations.

5. Supplemental Material

5.1 Adding education

The projected ART age-specific fertility rates for the period 2017-2022 were first estimated for women with low, medium and high education, and then aggregated to produce total ART fertility rates based on the educational composition of the individual cohorts. Below we describe the data and methodological approach used to estimate ART fertility histories by education and report the results of such analysis.

Education-specific treatment rates are estimated using an indirect estimation method, consisting of the following steps: a) calculation of the proportion of women of parity 0 and parity 1 and above by educational group from the census; b) distribution of ART treatments across educational groups based on parity information; c) calculation of treatment rates by education; d) estimation of ART ASFR by education obtained by multiplying treatment rates by success rates. Since there is no evidence that ART success rates vary by education, the same success rates have been used for all educational groups. Total assisted ASFRs are obtained by: 1) splitting each cohort of women in three groups according to their educational attainment in 2016, and 2) assigning to each group the estimated education-specific ART fertility pattern. Because the use of ART is more common among first-born children and highly educated women make up the largest share of childless women at all ages above 30, a higher proportion of ART births is assigned to tertiary educated women (Fig. 9). The 2016 Australian Census of Population and Housing (Census) microdata, accessed through TableBuilder Pro (ABS 2021), are used to assess the educational composition of the cohorts of women born in 1968-1986. Hence, information about women’s educational attainment corresponds to their educational level in 2016, when they were aged between 30 and 48 years old. These estimates are likely to largely also reflect their level of education at the end of the reproductive life, as the majority of women has already entered the last stage of education by the age of 30. Educational attainment is separated into three educational groups: low for women with primary and lower secondary education; medium for women with upper- and post-secondary education; and high for women with any tertiary degree obtained through university.

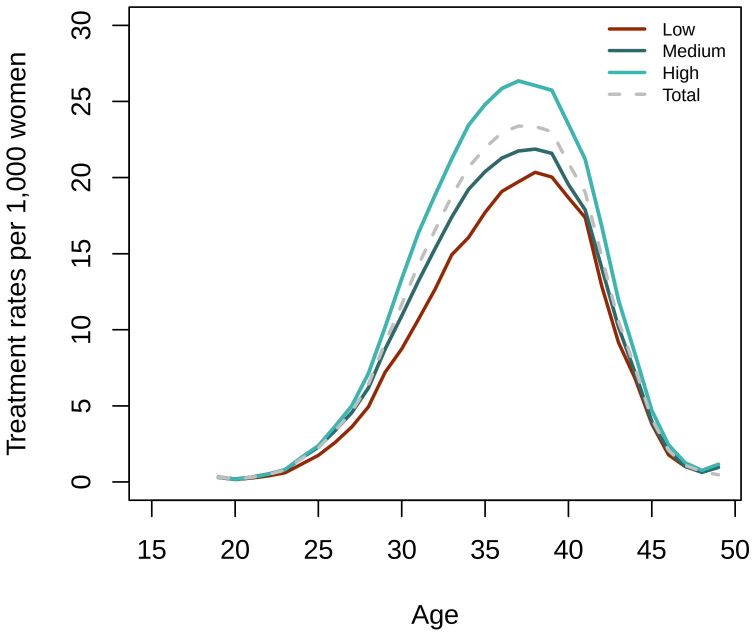

Fig. 9 *ART age-specific treatment rates, 2016, Australia.*

Source: Authors' computations based on the 2016 Australian Census of Population and Housing microdata and ANZARD data. Note: Educational attainment was measured using three categories, based on the Australian Standard Classification of Education (ASCED): low for women with certificate and Year 11 or below qualifications; medium for women with Year 12 and diploma qualifications; and high for women with any tertiary degree obtained through university.

In Fig. 10, the proportions of the population with low, medium and high education are presented for 1968-1986 cohorts. It is apparent that a substantial increase in the proportion of women with tertiary degrees occurred over the cohorts under investigation: from slightly less than 30% to 45%.

The second piece of information collected to estimate education-specific ART fertility rates are the proportions of childless women and of women with one or more children by educational group, also sourced from the 2016 Census (ABS 2021). This allow us to create a connection between records in the ANZARD database and in the 2016 Census based on parity information and to redistribute ART births across low, medium and high educated women. Overall, the adoption of this alternative method that takes into account educational composition does not substantially alter our results (as shown in Table 3) and confirms the robustness of our findings.

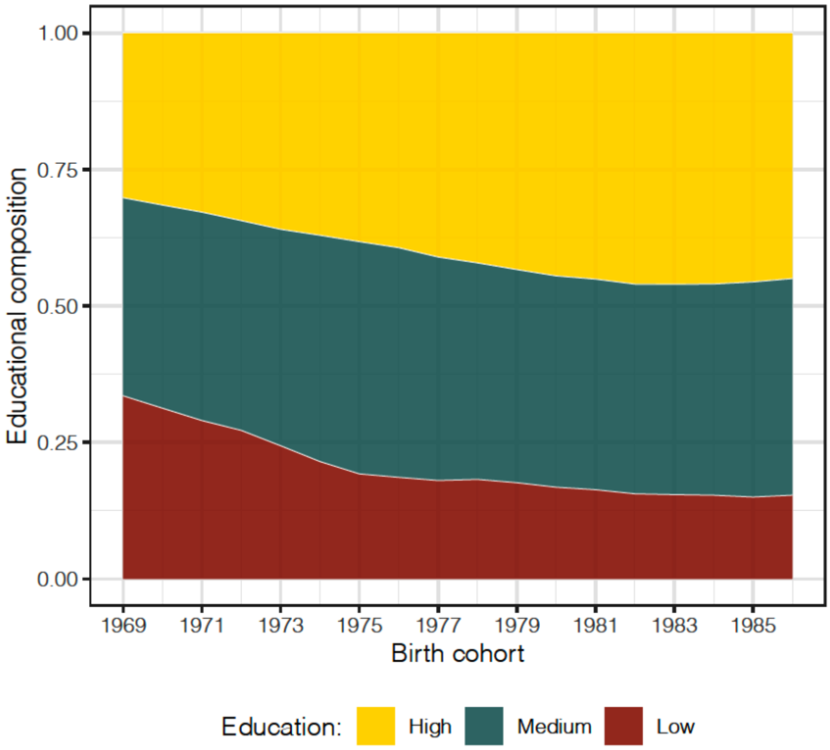

Fig. 10 *Educational composition among women born in 1968-1986, Australia.*

Source: Authors' computations based on the 2016 Australian Census of Population and Housing microdata. Note: Educational attainment was measured using three categories, based on the the Australian Standard Classification of Education (ASCED): low for women with certificate and Year 11 or below qualifications; medium for women with Year 12 and diploma qualifications; and high for women with any tertiary degree obtained through university.

Table 3 *Estimated percentage effect of ART use on the CFR according to five scenarios, Australian women born 1968-1986.* *Source:* Authors' computations based on ANZARD and ABS data.

Birth cohort	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
1968	2.07	2.07	2.07	2.07	2.07
1969	2.26	2.26	2.26	2.26	2.26
1970	2.48	2.48	2.48	2.49	2.49
1971	2.69	2.70	2.70	2.70	2.71
1972	2.90	2.91	2.91	2.92	2.94
1973	3.14	3.16	3.15	3.18	3.22
1974	3.40	3.43	3.42	3.45	3.56
1975	3.65	3.69	3.68	3.73	3.90
1976	3.82	3.87	3.86	3.92	4.18
1977	3.95	4.00	4.00	4.08	4.39
1978	4.07	4.14	4.16	4.25	4.60
1979	4.18	4.28	4.31	4.44	4.77
1980	4.32	4.42	4.50	4.63	4.96
1981	4.39	4.50	4.62	4.76	5.10
1982	4.42	4.52	4.72	4.85	5.19
1983	4.44	4.53	4.79	4.92	5.26
1984	4.58	4.68	5.01	5.14	5.48
1985	4.62	4.71	5.10	5.22	5.56
1986	4.67	4.75	5.21	5.31	5.66

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